PROCESS FOR MANUFACTURING A MICROMACHINED OSCILLATING ELEMENT, IN PARTICULAR A MIRROR FOR OPTICAL SWITCHES

PRIORITY CLAIM

[1] This application claims priority from Italian patent application No. TO2002A000565, filed June 28, 2002, which is incorporated herein by reference.

TECHNICAL FIELD OF THE INVENTION

[2] The present invention relates generally to a process for manufacturing a micromachined oscillating element, in particular a mirror for optical switches.

BACKGROUND OF THE INVENTION

[3] As is known, in optical-fibre communication systems, in order to avoid conversion of optical signals into electronic signals and the subsequent conversion of electronic signals into optical signals, it is desirable to have miniaturized devices for addressing and switching optical signals. Advantageously, the addressing and switching devices must be activatable by electrical signals generated by electronics associated with the devices, which are preferably integrated.

[4] To this aim, it has been proposed to manufacture small mobile reflecting surfaces (mirrors) employing micro-electromechanical-machining technologies used for microelectromechanical devices (MEMs). In particular, the mirrors may have just one degree of freedom (they are able to rotate about just one axis) for making two-dimensional switches, or two degrees of freedom (they are able to rotate about two axes) for making three-dimensional switches. Different processes have been proposed for making optical-switching devices of the type referred to above; however, these processes are rather complex and present some limitations.

[5] For example, EP-A-I 180 848 describes a process for manufacturing a switch, wherein the rotation of a mirror element is obtained by converting a translational motion generated by a linear actuator through a conversion assembly or joint arranged between the mirror element and the actuator.

[6] A further process, implemented by the present applicant, enables the manufacture of a mirror element formed by a reflecting platform and a plurality of

fingers (mobile electrodes), which are biased at a potential with respect to fixed electrodes so as to cause an attraction between some of the fixed electrodes and the mobile electrodes and hence a rotation of the mirror element. According to this process, the fixed electrodes are formed in a first wafer, the mirror element with the mobile electrodes are formed in a second wafer, bonded to the first wafer and appropriately thinned, and the portion of the first wafer underneath the platform is removed from the back after bonding the second wafer to a third temporary handling wafer.

[7] The above process is disadvantageous in that, in addition to being on the whole rather complex, it involves etching of the silicon of the first wafer throughout its thickness with the purpose of freeing the mirror element. In addition, it entails the formation of openings in the second wafer for accessing the first wafer and appropriately biasing the fixed electrodes. This is disadvantageous in that the contacts to the fixed electrodes are at a different level from the contacts to the mobile electrodes and to other possible structures, thus creating problems in the testing step. In addition, the first wafer is all at a same potential (the potential of the stator), and this may create problems after assembly on a board if there are leakages.

SUMMARY OF THE INVENTION

[8] An embodiment of the present invention improves the foregoing procedures so as to overcome the disadvantages.

[9] According to this embodiment of the present invention there are provided a micromachined device and the relative manufacturing process.

BRIEF DESCRIPTION OF THE DRAWINGS

[10] For an understanding of the present invention two preferred embodiments thereof are now described, purely by way of non-limiting example, with reference to the attached drawings, wherein:

[11] **FIGS. 1-3** show a cross-section through a first wafer of semiconductor material, taken along line III-III of Figure 4, in different fabrication steps;

[12] **FIG. 4** is a top plan view of the wafer of **FIG. 3**;

[13] **FIGS. 5-8** show a cross-section similar to that of **FIGS. 1-3**, after bonding the first wafer to a second wafer, in successive fabrication steps;

[14] **FIG. 9** is a top plan view of the composite wafer of **FIG. 8**;

[15] **FIG. 10** is a cross-section of the composite wafer of **FIG. 8**, taken along the line X-X of **FIG. 9**;

[16] **FIG. 11** shows a cross-section of the oscillating mirror element, taken along line XI-XI of **FIG. 9**, in a final fabrication step;

[17] **FIG. 12** is a perspective view of the mirror element of **FIG. 11**;

[18] **FIG. 13** illustrates a variant of **FIG. 5**; and

[19] **FIG. 14** is a cross-section of the variant of **FIG. 13**, in a final fabrication step.

DETAILED DESCRIPTION

[20] The following discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

[21] According to **FIG. 1**, a first wafer ***1*** formed by a substrate ***2*** of monocrystalline semiconductor material (silicon) is subjected to oxidation, to form a first insulating layer ***3*** and a second insulating layer ***4*** of silicon dioxide, respectively on the front and on the rear of the wafer.

[22] The first insulating layer ***3*** is then removed selectively to form contact openings ***5*** where the electrical contact is to be made between the substrate ***2*** and an intermediate layer, grown subsequently, as explained hereinafter. In particular, **FIG. 1** shows three contact openings ***5***, at two stator regions and at an external region, as is better clarified hereinafter.

[23] Subsequently, **FIG. 2**, on the front of the wafer ***1***, an intermediate layer ***8*** of polycrystalline silicon, obtained by deposition of an intermediate silicon layer or by deposition of a germ layer and subsequent epitaxial growth, is formed in a per se known manner. The intermediate layer ***8*** has, for example, a thickness of 50-100 μm and fills the contact openings ***5*** with contact portions ***6***, which thus electrically connect the intermediate layer ***8*** to the substrate ***2***. In a way not shown, on the back of the wafer ***1*** alignment marks are formed, necessary for the subsequent steps.

[24] After planarization through chemical-mechanical polishing (CMP), the wafer ***1*** is subjected (**FIG. 3**) to a masking and reactive ion etching (RIE) step, so as to form a cavity ***9*** and first electrical separation trenches ***10***. The shapes of the cavity ***9*** and of the first trenches ***10*** are shown in **FIG. 4**, which highlights with a dashed line also the shape of the contact portions ***6***. In this way, the intermediate layer ***8*** is here divided into a bottom outer region ***11***, a first bottom stator region ***12a*** and a second bottom stator region ***12b***. Fixed electrodes ***13a***, ***13b*** extend, respectively, from the first stator region ***12a*** and from the second stator region ***12b*** towards the inside of the cavity ***9***.

[25] The first wafer ***1*** is turned upside down and bonded, in a per se known manner, to a second wafer ***15*** comprising a semiconductor body ***16*** and a bonding oxide layer ***17***, to obtain a composite wafer ***20***, as illustrated in **FIG. 5**.

[26] Hereinafter (**FIG. 6**), the first wafer ***1*** undergoes lapping and CMP so as to reduce the thickness of the substrate ***2*** to approximately 50-l00 μm.

[27] On the free surface ***21*** (**FIG. 7**), thus formed, of the first wafer ***1*** two metal layers, for example a first aluminium layer to form metallizations and a second chrome-gold layer to form a mirror surface (not shown), are then deposited and defined. In this way, metal contacts ***22*** (indicated with dashed lines in that they are arranged on a plane or planes different from the cross-sectional one) are formed, with the purpose of enabling biasing of the different portions of the finished device.

[28] Subsequently, in **FIG. 8**, the substrate ***2*** of the first wafer ***1*** is etched with a trench etch, which stops automatically on the first insulating layer ***3***. Second trenches ***23***, the shape whereof is shown in **FIG. 9**, are thus formed. The second trenches ***23***, which are in part aligned to the first trenches ***10***, separate from one

another a mirror element ***25***, a top outer region ***27***, a top stator region ***28a***, and a second top stator region ***28b***. The mirror element ***25*** is formed by a platform ***30***, a pair of arms or supporting springs ***31***, anchoring regions ***32***, and mobile electrodes ***33a***, ***33b***; the platform ***30***, the supporting arms ***31***, and the mobile electrodes ***33a***, ***33b*** extending above the cavity ***9*** and forming an oscillating element ***34***. The oscillating platform ***30*** forms a reflecting surface used for switching an optical beam. A metal contact ***22*** is present on at least one of the anchoring regions ***32***, as may be seen also from **FIG. 10**. In the example illustrated, the mobile electrodes ***33a***, ***33b*** extend directly from the platform ***30*** toward the top stator regions ***28a***, ***28b*** in a staggered way with respect to the fixed electrodes ***13a***, ***13b*** and, precisely, comb-fingered with respect to the latter in top plan view, even though they are formed on different planes.

[29] Finally, portions of the first insulating layer ***3*** are removed through the second trenches ***23*** by an RIE etch. In practice, the first insulating layer ***3*** is removed underneath the oscillating element ***34***, where the cavity ***9*** is present, so as to free the platform ***30***, the mobile electrodes ***33a***, ***33b***, and the supporting arms ***31***, as illustrated in the **FIG. 11**, which shows a cross-section taken on a plane different from that of the previous figures, and indicated by XI-XI in **FIG. 9**. In addition, the first insulating layer ***23*** is removed between the top outer region ***27*** and the first and second top stator regions ***28a***, ***28b***, separating completely said regions from one another.

[30] Thus the final structure of **FIGS. 11** and **12** is obtained. In particular, in **FIG. 11**, the mirror element ***25*** is represented with a solid line in the resting position, with the platform ***30*** coplanar to the top stator regions ***28a***, ***28b***, and with a dashed line in the inclined position. The inclined position shown in **FIGS. 11** and **12** is obtained by appropriately biasing the top stator regions ***28a***, ***28b*** and the anchoring region ***32*** (through the metal contacts ***22***) so as to create an attractive force between the fixed electrodes ***13a*** and the mobile electrodes ***33a***.

[31] According to a different embodiment of the process, the second wafer ***15*** houses the electrical components necessary for controlling the position of the platform ***30***. To this aim, the bonding between the first wafer ***1*** and the second wafer

15 must enable electrical connection between the bottom outer region ***11*** and the bottom stator regions ***12a***, ***12b***, and the relative components in the second wafer ***15***. In detail, as illustrated in **FIG. 13** and in a per se known manner, the second wafer ***15*** is machined so as to integrate the electronic components, represented in **FIG. 13** by conductive regions ***40*** having a conductivity opposite to the substrate ***16***. An oxide layer ***41*** is formed on top of the upper surface of the substrate ***16***, electrical-connection regions ***42*** of metal are formed inside the oxide layer ***41***, and pads ***43***, for example of palladium, are formed above the oxide layer ***41***, in regions ***11***, ***12a***, ***12b*** of the first wafer ***1***. In addition, as shown in the portion to the left in **FIG. 13**, bonding regions ***45*** are formed, simultaneously to the pads ***43***, where a mechanical connection isdesired between the second wafer ***15*** and the first wafer ***1***.

[32] Then, similar to what was described with reference to **FIG. 5**, the first wafer ***1*** is turned upside down and bonded to the second wafer ***15***. In particular, where the pads ***43*** and the bonding regions ***45*** are present, they form a bond with the silicon of the intermediate layer ***8***, electrically connecting the regions ***11***, ***12a***, ***12b*** to the conductive regions ***40*** through the electrical-connection regions ***42***. In the bonding regions ***45*** there is, instead, a pure mechanical bonding. In addition, as may be noted in **FIGS. 13** and **14**, above the bonding regions ***45*** the first insulating layer ***3*** is continuous, insulating the portion ***53*** of the intermediate layer from the substrate ***2***. Then, the process proceeds with steps similar to the ones described with reference to **FIGS. 6-12**, except for that, when the second trenches ***23*** are made, circular openings are also formed around the pads ***22*** used for contacting the electronic components (conductive regions ***40***), and then these circular openings are filled with dielectric material ***50*** so as to insulate silicon plugs ***51*** from the rest of the substrate ***2***, as shown in **FIG. 14**.

[33] The advantages of the described process and device are indicated hereinafter. First, the process is simple and involves the bonding of just two wafers to obtain the mirror element.

[34] All the regions are electrically insulated from one another; in particular, the anchoring regions ***32*** of the mirror element ***25*** are insulated from the underlying regions by an oxide layer (first insulating layer ***3***) and the outer region ***11***, ***27***, the

first stator region ***12a***, ***28a***, and the second stator region ***12b***, ***28b*** are insulated from one another and with respect to the second wafer ***15***. This also enables integration of electronic components in the substrate ***2***, which is monocrystalline.

[35] All the contacts are arranged at the same level, on the surface ***21*** of the substrate ***2***; consequently, the operations of contacting and testing are facilitated and it is possible to test the mirror element ***25*** in an electrical wafer sorting (EWS) step.

[36] Freeing of the oscillating element ***34*** is obtained without the need to remove the underlying substrate from the backside; consequently, the procedure is simpler and more economical, and the final structure is sturdier.

[37] The embodiments of micromachined devices described above with reference to **FIGS. 1-14** may be incorporated into an integrated circuit, which may, in turn, be incorporated into an electronic system such as an optical communications system.

[38] Finally, it is clear that numerous modifications and variations can be made to the process and device described and illustrated herein, all of which fall within the scope of the invention, as defined in the attached claims.